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(56) Documents Cited
EP 1136310 A
EP 0754588 A
JP 010073161 A
JP 2001103602 A
US 4730151 A

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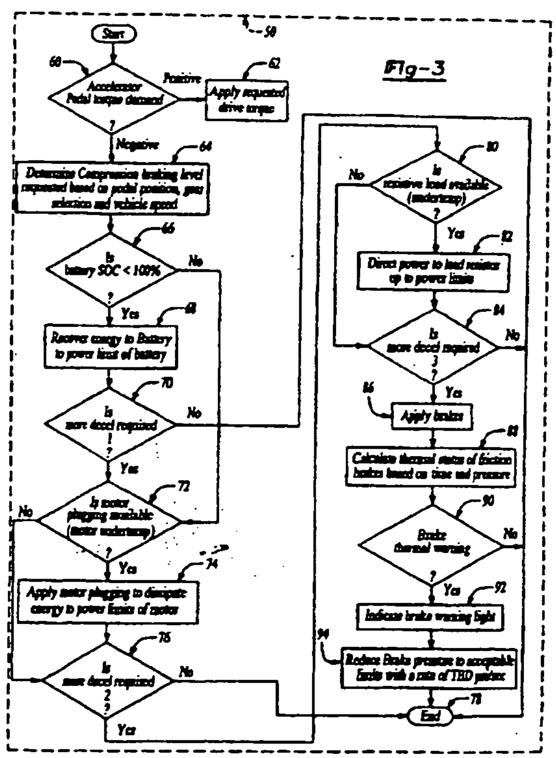
(54) Abstract Title
"Engine braking feel" for an electric motor of a hybrid powertrain

(57) The system includes a vehicle system controller arranged to provide negative torque to the vehicle when only the electric motor is engaged and an accelerator pedal is released. This deceleration uses a hierarchical strategy employing a variety of means including dissipating the vehicle's kinetic energy as heat in the electric motor, regenerative braking, and activating a mechanical friction braking system. The system is arranged to provide the driver of the vehicle with a deceleration response similar in "feel" to releasing the accelerator of a conventional internal combustion engine powered vehicle.



At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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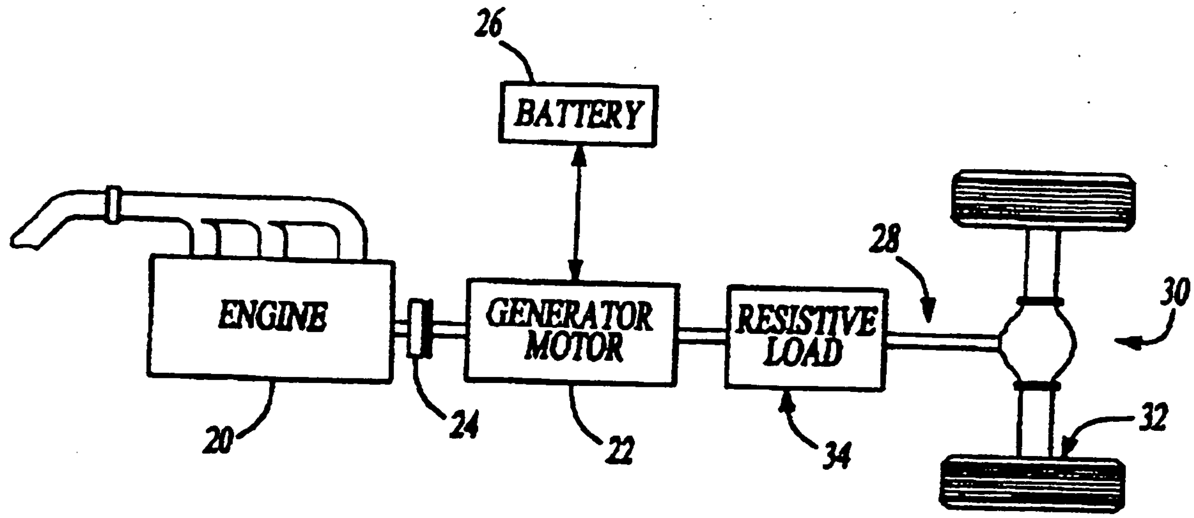

26
BATTERY
ENGINE
GENERATOR MOTOR
RESISTIVE LOAD
28
30
20
24
22
34
32

Fig-1

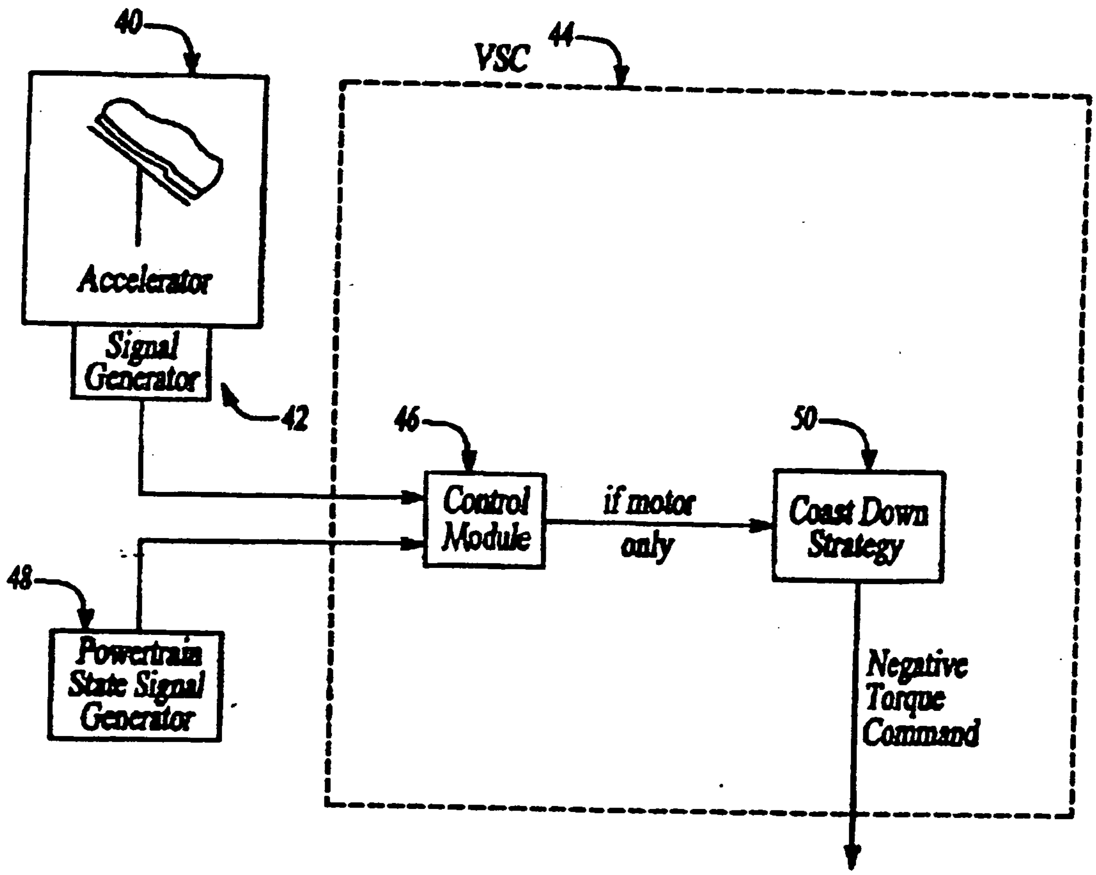
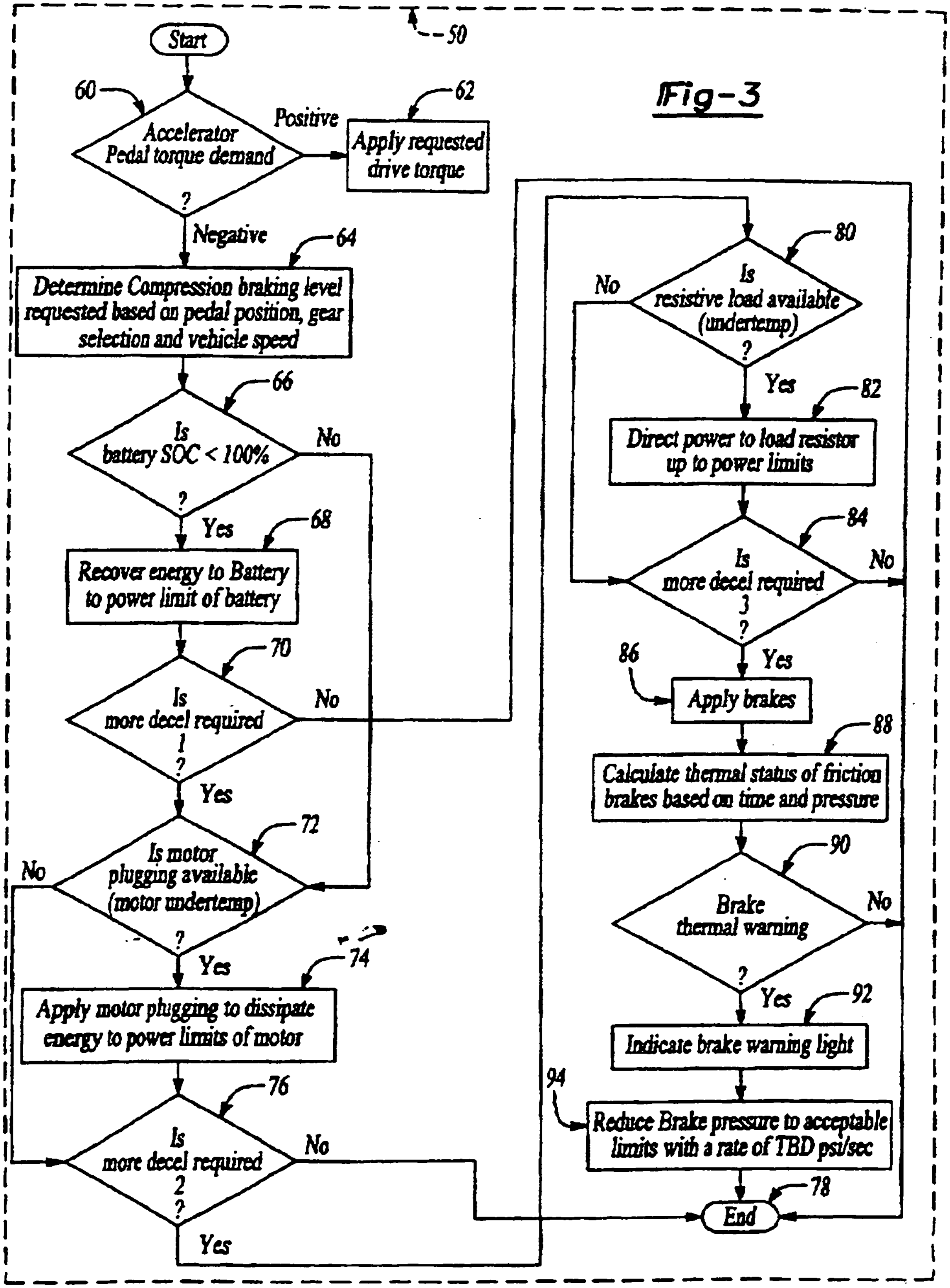

40
VSC
44
Accelerator
Signal Generator
42
46
Control Module
if motor only
50
Coast Down Strategy
48
Powertrain State Signal Generator
Negative Torque Command

Fig-2



50
Fig-3
Start
60
Accelerator Pedal torque demand ?
Positive
62
Apply requested drive torque
Negative
64
Determine Compression braking level requested based on pedal position, gear selection and vehicle speed
66
Is battery SOC < 100% ?
No
Yes
68
Recover energy to Battery to power limit of battery
70
Is more decel required 1 ?
No
Yes
72
Is motor plugging available (motor undertemp) ?
No
Yes
74
Apply motor plugging to dissipate energy to power limits of motor
76
Is more decel required 2 ?
No
Yes
80
Is resistive load available (undertemp) ?
No
Yes
82
Direct power to load resistor up to power limits
84
Is more decel required 3 ?
No
Yes
86
Apply brakes
88
Calculate thermal status of friction brakes based on time and pressure
90
Brake thermal warning ?
No
Yes
92
Indicate brake warning light
94
Reduce Brake pressure to acceptable limits with a rate of TBD psi/sec
78
End

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A MOTOR VEHICLE AND A METHOD AND SYSTEM THEREFOR

The invention relates to motor vehicles and in particular to a motor vehicle having an electric drive motor such as a battery powered electric vehicle (EV),a hybrid electric vehicle (HEV) or a fuel cell electric vehicle (FCEV), and in particular a hierarchical method and system to produce negative powertrain torque (deceleration force) when an accelerator pedal is released and only the electric motor is providing torque to the powertrain.

The need to reduce fossil fuel consumption by and pollutants from automobiles and other vehicles powered by an internal combustion engine (ICE) is well known. Vehicles powered by electric motors attempt to address these needs. However, electric vehicles have limited range and limited power capabilities and need substantial time to recharge their batteries.

An alternative solution is to combine both an ICE and electric traction motor into one vehicle. Such vehicles are typically called hybrid electric vehicles (HEV's). See generally, U.S. Pat. No. 5,343,970 (Severinsky).

The HEV has been described in a variety of configurations. Many HEV patents disclose systems where an operator is required to select between electric and internal combustion operation. In other configurations, the electric motor drives one set of wheels and the ICE drives a different set.

Other, more useful, configurations have developed. For example, a series hybrid electric vehicle (SHEV) is a vehicle with an engine (most typically an ICE) that powers a generator. The generator, in turn, provides electricity for a battery and an electric traction motor coupled to the

drive wheels of the vehicle. There is no mechanical connection between the engine and the drive wheels.

Further, a parallel hybrid electrical vehicle (PHEV) is a vehicle with an engine (most typically an ICE), battery, and electric traction motor that combine to provide torque to the drive wheels of the vehicle.

A parallel/series hybrid electric vehicle (PSHEV) has characteristics of both the PHEV and the SHEV. The PSHEV is also known as a torque (or power) split powertrain configuration. Here, the engine torque can be used to power a generator and/or contribute to the necessary wheel or output shaft torque. Further, the PSHEV reduces emissions and fuel consumption under certain conditions by turning the engine off. The PSHEV can be used to generate electricity to the battery or can contribute to the necessary wheel or output shaft torque. The traction motor is used to contribute to the necessary wheel or output shaft torque and can also be used to recover braking energy to the battery if a regenerative braking system is used.

The desirability of combining the ICE with an electric motor is clear. The ICE's fuel consumption and pollutants are reduced with no appreciable loss of performance or range of the vehicle. Nevertheless, there remains substantial room for development of ways to optimize HEV operation.

One such area of development is the improvement of the overall HEV drive-ability and feel consistent with traditional ICE vehicles. This is especially true when the HEV's engine is not contributing torque to the vehicle's powertrain or is not even running. When the electric motor is solely providing powertrain torque, there is very little or no drag on the powertrain after the driver releases a speed control such as an accelerator pedal. Typically, the driver of a traditional ICE vehicle expects a coast-down

force in vehicle speed when the accelerator pedal is released because of the effect of engine braking. Engine braking is well known and is typically characterized by two types of negative powertrain torque including engine friction and pumping (compression) losses.

Engine friction loss occurs during engine braking because the engine, although unfueled, is still connected to the powertrain. Engine pumping loss occurs because of the compression of air in each engine cylinder as it moves through its stroke.

Engine braking is expected by the driver and allows reduction of vehicle speed without applying force to the brake pedal and so also reduces the wear of the friction brakes fitted to the motor vehicle.

Various ways for an electric vehicle to simulate the ICE's negative torque when the accelerator is released are known in the prior art. For example in U.S. Patent No. 4,103,211 describes a system of providing a motor armature regenerative current path through a load resistor by maintaining motor field current when the speed control is released. The resistance element serves to limit the magnitude of the current produced by the armature and provide a power sink or load to absorb the regenerative energy. Thus, the combination of a function generator, a diode, and a resistance element acts to provide the expected negative powertrain torque. This invention also discloses that the system could be adapted for bi-directional motion (i.e., forward and reverse) by, for example, switches for reversing the motor field winding connections.

Regenerative braking (regen) causes vehicle coast-down by capturing the kinetic energy of the vehicle. In conventional vehicles, kinetic energy is usually dissipated

as heat at the vehicle's brakes or engine during deceleration.

Regen converts the captured kinetic energy, through a generator, into electrical energy in the form of a stored charge in the vehicle's battery. Consequently, regen also reduces fuel usage and emission production.

In U.S. Patent No. 4,691,148, a control circuit for electric vehicles is described that includes applying regen during coasting and braking. The regen is switched on by releasing the accelerator or slightly engaging the brake pedal. Mechanical brakes are added when additional brake pedal force is applied. During this regenerative braking, the circuit between the battery pack and the motor must remain connected even though the accelerator pedal is released. Normally, the battery pack would be disconnected from the motor. The control circuit is calibrated to reduce speed gradually using regen when brake pedal braking is not desired.

U.S. Patent No. 5,578,911 describes a continuously variable regenerative control for an electric vehicle. The control provides the ability to tailor the regenerative (or braking) effect of the electric motor to match that of the internal combustion engine. This drivability characteristic is familiar to and desired by many vehicle operators.

Therefore although the desire and need for drivability feel when the accelerator is released is known, to some extent, for a solely electric vehicle, there is a need to develop a more sophisticated method and system for a consistent coast-down feel including all electric powertrain applications.

It is an object of this invention to provide a motor vehicle having a method and system with improved feel when the accelerator released.

According to a first aspect of the invention there is provided a control system for a vehicle having an electric drive motor, a powertrain, a friction braking system, an operator-movable accelerator means that is moveable between a released position and a full power position, an indicator means operably connected to the accelerator means to provide a signal indicative of when the accelerator means is at least in the released position, a powertrain indicator mean to provide a signal indicative of powertrain state and in particular when the electric motor is the sole source of torque to the powertrain wherein the control system comprises, a vehicle system controller, a control module within the vehicle system controller to receive an output from the accelerator indicator means accelerator position and the output from the powertrain indicator means, the control module being operable to determine when the accelerator means is at a released position and the electric motor is the sole source of torque to the powertrain and a coast-down control means operable to receive an output from the control module and arranged to command at least one source of negative torque to the vehicle powertrain when the control module has determined that the accelerator is released and that the electric motor is the sole torque provider to the powertrain.

The vehicle may be an electric vehicle, a hybrid electric vehicle or a fuel cell electric vehicle.

The coast-down control means may be operable to provide a negative torque to the powertrain that is calibrated in amount and duration to be similar to the negative torque expected by a driver of an internal combustion engine

powered vehicle when an engine accelerator pedal of such a vehicle is released.

The coast down control means may be operable to provide a negative torque to the powertrain by motor plugging so as to dissipate the kinetic energy of the vehicle as heat in the electric motor.

The coast-down control means may be operable to provide a negative torque to the powertrain by operating the electric motor as a generator which is used to generate electrical power.

The electrical power generated may be transmitted to a resistive load to dissipate energy or may be transmitted to a battery to recharge the battery thereby storing the energy.

The coast-down control means may be operable to provide negative torque to the powertrain by activating a friction braking system of the vehicle, whereby the vehicle's kinetic energy is dissipated as heat in the friction braking system.

The coast-down control means may be operable to utilise the friction braking system in a manner such that optimal energy recovery is maintained.

According to a second aspect of the invention there is provided a method of providing a negative torque to a powertrain of a vehicle with an electric motor, comprising the steps of releasing an accelerating means operator-movable through a range of distance from a released position to a full power position, transmitting when the accelerator means is at the released position to a vehicle system controller, transmitting a powertrain state to the vehicle system controller, determining when the electric motor is a sole source of torque to the powertrain and the accelerator

means is at a released position, and operating in accordance with a predetermined coast down strategy, whereby negative torque is applied to the vehicle powertrain.

The method may comprise calibrating the negative torque to the powertrain in an amount and duration equal to the negative torque expected by a driver of a traditional internal combustion engine based vehicle when an engine accelerator pedal is released.

The method may comprise dissipating the kinetic energy of the vehicle as heat in the electric motor.

The method may comprise of adding a resistive load to the powertrain by controlling the electric motor as a generator, whereby deceleration occurs from controlling the motor as a generator and generating electrical power to a resistive load to dissipate energy or to a battery to store the energy.

The method may comprise activating friction brakes, whereby the vehicle's kinetic energy is dissipated as heat in brake rotors and drums of the friction brakes.

The method may comprise maintaining optimal energy recovery.

Advantageously, the method may comprise determining the available sources of negative torque and applying them in a hierarchical manner.

The sources of negative torque are preferably applied in a manner so as to maintain optimum energy recovery and include utilising motor plugging followed by the use of a resistive load and then the use of friction braking.

According to a third aspect of the invention there is provided a motor vehicle having an electric drive motor, a powertrain, a friction braking system, a control system, an operator-movable accelerator means that is moveable between a released position and a full power position, an indicator means operably connected to the accelerator means to provide a signal indicative of when the accelerator means is at least in the released position, a powertrain indicator mean to provide a signal indicative of powertrain state and in particular when the electric motor is the sole source of torque to the powertrain wherein the control system comprises, a vehicle system controller, a control module within the vehicle system controller to receive an output from the accelerator indicator means accelerator position and the output from the powertrain indicator means, the control module being operable to determine when the accelerator means is at a released position and the electric motor is the sole source of torque to the powertrain and a coast-down control means operable to receive an output from the control module and arranged to command at least one source of negative torque to the vehicle powertrain when the control module has determined that the accelerator is released and that the electric motor is the sole torque provider to the powertrain.

The motor vehicle may be a hybrid motor vehicle having an internal combustion engine and an electric motor as sources of motive power and a clutch to disconnect the engine from the transmission.

The invention will now be described by way of example with reference to the accompanying drawing of which:-

Figure 1 illustrates the general components of a hybrid electric vehicle (HEV) powertrain with an engine disconnect clutch;

Figure 2 illustrates the major components of the HEV's vehicle system controller in accordance with the invention for providing negative torque (coast-down) when the accelerator is released and the electric motor is solely providing torque to the vehicle powertrain; and

Figure 3 is a decision flowchart showing a strategy in accordance with the invention.

The present invention is generally relates to all electric motor powered vehicles but is specifically described herein with reference to a parallel hybrid electric vehicle PHEV.

Figure 1 shows general components of a parallel PHEV powertrain with an engine disconnect clutch 24. An engine 20 is linked to an electric motor/generator 22 via the disconnect clutch 24. A battery 26 is connected to the motor/generator 22 and allows the flow of electrical current to and from the two components.

The motor/generator 22 is connected to a power transfer means 28, such as a drive shaft, which is connected a vehicle's wheels 30. Thus, torque energy flows from the engine 20 and motor/generator 22 through the power transfer means 28 to the wheels 30. A resistive load 34 is also attached to the power transfer means. The wheels 30 have mechanical brakes 32 to stop the vehicle as desired by an operator. Since the engine 20 can be disconnected from the motor/generator 22 and the power transfer means 28, there are three potential powertrain states.

These states are based on various vehicle demands and include the engine only, the motor only, or the engine and the motor combined.

The invention is relevant to the state when only the motor is connected to the power transfer means 28.

In figure 2, a general illustration of a possible strategy to determine an expected vehicle deceleration (coast-down) response feel in this powertrain state, similar to a conventional ICE vehicle when the accelerator pedal is released, is shown.

An accelerator 40 has an accelerator signal generator 42. Within a vehicle system controller (VSC) 44, a control module 46 receives input from the accelerator signal generator 42 and a powertrain state signal generator 48. If the control module 46 determines the accelerator 40 is released and the engine 20 is disconnected from the power transfer means 28, a command is sent to run a coast-down strategy 50.

The coast-down strategy 50 must be immediate and provided for only a brief time, thereby reducing the total energy dissipation but still providing expected vehicle response feel to the driver. The strategy will maximize energy recovery regenerative braking (regen) if the battery state of charge is below a certain level while maintaining a consistent and expected deceleration.

The strategy is adaptive and selects the appropriate coast-down configuration based upon vehicle operating conditions such as battery state of charge, engine/motor temperature, resistive load temperature, such that deceleration is consistent regardless of operating conditions. The system configuration may contain some or all of strategies.

The strategy utilises three methods for providing negative torque "motor plugging", "resistive load" and "friction load".

Motor plugging provides negative torque to the powertrain by dissipating the kinetic energy of the vehicle as heat in the motor/generator 22 as described in the prior art. This strategy involves operating the motor inefficiently. The controller is essentially causing the motor to burn power by using high flux levels in the motor windings.

Resistive load requires the addition of a resistive load to the powertrain by controlling the motor/generator 22 as a generator. In this strategy, electrical power is generated to a resistive load that dissipates the energy or to the battery 26 to store the energy.

Friction load requires the activation of the mechanical brakes 32 that are used to dissipate the vehicle's kinetic energy as heat in the brake rotors and drums.

The coast-down strategy 50 shown in Fig. 3 preferably combines all three methods described above.

First, an accelerator pedal torque demand 60 is determined from the accelerator 40 position. A positive torque demand results in an apply requested drive torque 62 command. Negative torque demand results in a determination of compression braking level 64 that determines amount of compression braking based on the accelerator 40 position, gear selection (i.e., PRNDL) and vehicle speed.

Since the coast-down strategy 50 optimally is intended to recover the energy, the battery 26 is selected to store the energy. Therefore, once compression braking level 64 is determined, the battery state-of-charge (SOC) 66 is determined.

If a battery SOC 66 is below 100 per-cent, a recover energy to battery 68 command results, whereby the system

seeks to recover as much kinetic energy to the battery 26 within a pre-determined a power limit or charging rate of the battery 26.

If the battery SOC 66 is at 100%, the procedure is to dissipate the energy directly in the motor/generator 22 up to its available limits.

If the recover energy to battery 68 command results in reaching the power limit of the battery 26, a first determination of the need for more deceleration 70 results.

If no more deceleration is required, then an end strategy 78 will be the result.

If more deceleration is needed, a motor plugging availability determination 72 is made based on motor/generator 22 temperature compared against a predetermined threshold. If motor plugging is available because the motor/generator 22 is below a pre-determined temperature threshold then a motor plugging command 74 is applied to dissipate energy to the power limits of the motor/generator 22.

When the power limits of the motor/generator 22 are reached, a second determination of a need for more deceleration 76 is made. This second determination of the need for more deceleration 76 also receives the output of the motor plugging availability determination 72 when the motor/generator 22 is over the threshold temperature.

If the second determination of the need for more deceleration 76 indicates that ,no, more deceleration is not required then an end strategy 78 will be the result.

If the second determination of the need for more deceleration 76 indicates that more deceleration is required then, a resistive load determination 80 is made.

Temperature of the resistive load 34 is compared against a predetermined threshold value and if the temperature is sufficiently low then the resistive load 34 is available.

A command 82 is then sent to direct power to the resistive load until the power limits of the resistive load 34 are reached. Once the power limits of the resistive load 34 are reached, a third determination of the need for more deceleration 84 is made.

If the second determination of the need for more deceleration 84 indicates that more deceleration is not required then the end strategy 78 will be the result.

This third determination 84 also receives the output of the resistive load availability determination 82 when the resistive load 34 is over the threshold temperature.

If the determination indicates that more deceleration is required after this third determination 84, the strategy goes to an apply brake command 86 , whereby the mechanical friction brakes 32 are applied.

As the mechanical brakes 32 are applied, the strategy makes a calculation of thermal status of the mechanical brakes 88, whereby the status of the brakes 32 are calculated based on braking duration and pressure. This calculation results in a brake thermal warning determination 90 based on a predetermined temperature threshold.

If the thermal brake warning 90 is "No", the end strategy 78 results.

If the thermal brake warning 90 is "Yes", a brake warning light 92 is activated, followed by a reduction of brake pressure command 94, whereby brake 32 pressure is reduced at an acceptable rate to predetermined acceptable limits and ultimately to the end of the strategy 78.

It will be appreciated that the above embodiment is illustrative and that various modifications or variation can be made without deviating from the scope of the invention.

CLAIMS

1. A control system for a vehicle having an electric drive motor, a powertrain, a friction braking system, an operator-movable accelerator means that is moveable between a released position and a full power position, an indicator means operably connected to the accelerator means to provide a signal indicative of when the accelerator means is at least in the released position, a powertrain indicator mean to provide a signal indicative of powertrain state and in particular when the electric motor is the sole source of torque to the powertrain wherein the control system comprises, a vehicle system controller, a control module within the vehicle system controller to receive an output from the accelerator indicator means accelerator position and the output from the powertrain indicator means, the control module being operable to determine when the accelerator means is at a released position and the electric motor is the sole source of torque to the powertrain and a coast-down control means operable to receive an output from the control module and arranged to command at least one source of negative torque to the vehicle powertrain when the control module has determined that the accelerator is released and that the electric motor is the sole torque provider to the powertrain.

2. A control system as claimed in claim 1, wherein the coast-down control means is operable to provide a negative torque to the powertrain that is calibrated in amount and duration to be similar to the negative torque expected by a driver of a internal combustion engine powered vehicle when an engine accelerator pedal of such a vehicle is released.

3. A control system as claimed in claim 1 or in claim 2 in which the coast down control means is operable to provide a negative torque to the powertrain by motor

plugging so as to dissipate the kinetic energy of the vehicle as heat in the electric motor.

4. A control system as claimed in any of claims 1 to 3 in which the coast-down control means is operable to provide a negative torque to the powertrain by operating the electric motor as a generator which is used to generate electrical power.

5. A control system as claimed in claim 4 in which the electrical power generated is transmitted to a resistive load to dissipate energy.

6. A control system as claimed in claim 4 in which the electrical power generated is transmitted to a battery to recharge the battery thereby storing the energy.

7. A control system as claimed in claim 1, in which the coast-down control means is operable to provide negative torque to the powertrain by activating a friction braking system of the vehicle, whereby the vehicle's kinetic energy is dissipated as heat in the friction braking system.

8. A method of providing a negative torque to a powertrain of a vehicle with an electric motor, comprising the steps of releasing an accelerating means operator-movable through a range of distance from a released position to a full power position, transmitting when the accelerator means is at the released position to a vehicle system controller, transmitting a powertrain state to the vehicle system controller, determining when the electric motor is a sole source of torque to the powertrain and the accelerator means is at a released position, and operating in accordance with a predetermined coast down strategy, whereby negative torque is applied to the vehicle powertrain.

9. A motor vehicle having an electric drive motor, a powertrain, a friction braking system, a control system, an operator-movable accelerator means that is moveable between a released position and a full power position, an indicator means operably connected to the accelerator means to provide a signal indicative of when the accelerator means is at least in the released position, a powertrain indicator mean to provide a signal indicative of powertrain state and in particular when the electric motor is the sole source of torque to the powertrain wherein the control system comprises, a vehicle system controller, a control module within the vehicle system controller to receive an output from the accelerator indicator means accelerator position and the output from the powertrain indicator means, the control module being operable to determine when the accelerator means is at a released position and the electric motor is the sole source of torque to the powertrain and a coast-down control means operable to receive an output from the control module and arranged to command at least one source of negative torque to the vehicle powertrain when the control module has determined that the accelerator is released and that the electric motor is the sole torque provider to the powertrain.

10. A motor vehicle as claimed in claim 10 in which the motor vehicle is a hybrid motor vehicle having an internal combustion engine and an electric motor as sources of motive power and a clutch to disconnect the engine from the transmission.

11. A control system for a vehicle substantially as described herein with reference to the accompanying drawing.

12. A method of providing a negative torque to a powertrain of a vehicle with an electric motor substantially as described herein with reference to the accompanying drawing.

13. A motor vehicle substantially as described herein with reference to the accompanying drawing.

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19

INVESTOR IN PEOPLE

Application No: GB 0122307.2
Claims searched: 1 to 13

Examiner: Jason Clee
Date of search: 27 February 2002

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.T): NONE

Int Cl (Ed.7): B60K: 6/04 & 41/20
B60L: 7/08, 7/18 & 7/26
B60T: 1/10
H02P 3/12, 3/14 & 3/16

Other: Online: WPI, EPODOC & JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	EP 1136310 A	(Sumitomo Brake Systems) especially see the abstract	1, 2, 4, 6, 8-10
X	EP 0754588 A	(Toyota Motor Co. Ltd) especially see the abstract and figures	1, 2, 4, 6 & 8-10
X	US 4730151	(General Electric) especially see the abstract and column 3 lines 12 to 14	1, 2, 4 & 6-10
X	JP 2001103602 A	(Suzuki Motor Corporation) especially see the abstract	1, 2, 4, 6, 8-10
X	JP 10073161 A	(Toyota Motor Corporation) especially see the abstract	1, 2, 4, 6, 8-10

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Y Document indicating lack of inventive step if combined with one or more other documents of same category.
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E Patent document published on or after, but with priority date earlier than, the filing date of this application.